

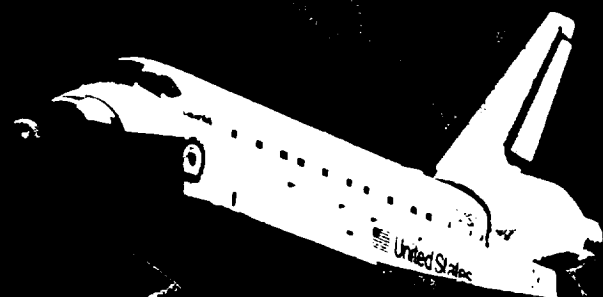


(NASA-TM-109043) EARTH BENEFITS
FROM NASA RESEARCH AND TECHNOLOGY.
LIFE SCIENCES APPLICATIONS (NASA)
36 p

63-10712

Unclass

63/85 014241



Earth Benefits from NASA Research and Technology

Life Sciences Applications

Earth Benefits
from
NASA Research and Technology
Life Sciences Applications

October 1991

Prepared for the
NASA Office of Space Science and Applications
Life Sciences Division



For further information

National Aeronautics and Space Administration
Life Sciences Division
Code SB
Washington, DC 20546

Table of Contents-

Foreword 1

Introduction2-4

Life Sciences Applications:

Medicine and Health Care5-21

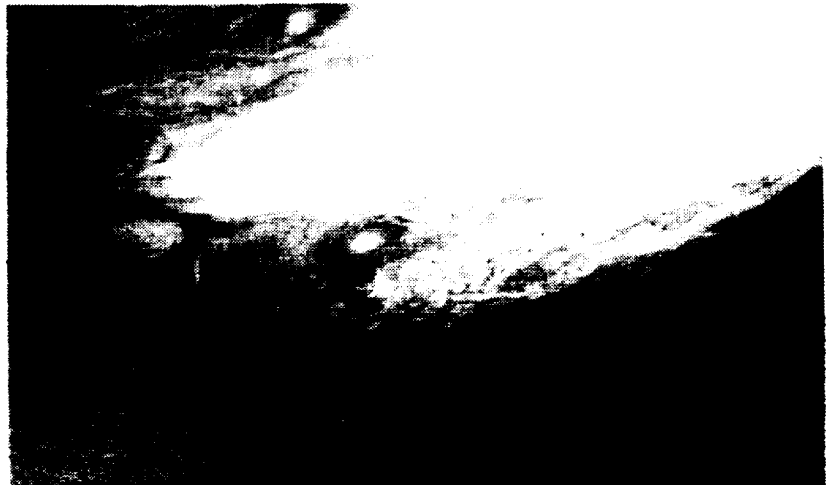
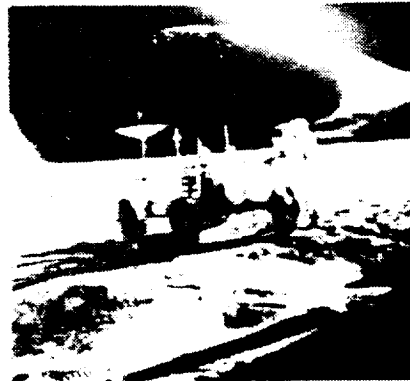
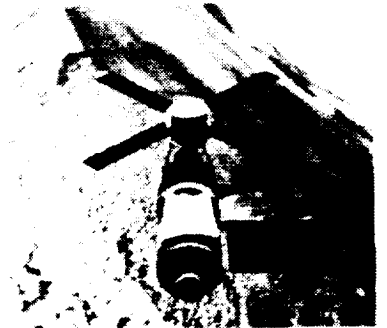
Environmental Monitoring, and Safety22-24

Agricultural Productivity25-27

Environmental Protection28-32

Bibliography33

PRECEDING PAGE BLANK NOT FILMED



The U.S. space program—a record of scientific and technological achievements. Clockwise: Voyager image of Saturn; Skylab; Apollo's lunar rover; Viking on Mars; Voyager image of Jupiter; Gemini crewmember engaged in extravehicular activity; the U.S. Space Shuttle.

Foreword

Many applications of space research and technology have, since NASA's beginnings in 1958, improved the quality of life on Earth in numerous areas. Foremost among these contributions have been those to medicine and health care. Perhaps the most dramatic impact in this group occurred in the field of biotelemetry, where miniaturization and computer enhancement have made it practical for patients to have their heart and other vital functions monitored at considerable distances by means of radio frequencies. Other major improvements have been made in medical imaging, computer technology, transportation, public safety, mobility systems for the physically handicapped; materials for containers, surgical equipment and prostheses; and information vital to environmental protection.

Over the past three decades NASA-derived technology has been the basis for an estimated 30,000 spin-offs. In a study sponsored by NASA and conducted by the Chapman Research Group, published in 1989, respondents acknowledged contributions of NASA-sponsored or provided technology toward savings or sales in 83% of the cases investigated. Further research showed that the 259 cases studied generated benefits amounting to almost \$22 billion in combined product sales and savings to the companies. Based on the sales data, Federal income tax revenues were estimated at almost \$356 million.*

While the figures cited in the Chapman Report are impressive and certainly illustrate the efficacy of the technology transfer process, the full extent of the influence of space research and development throughout the history of the U.S.

space program has undoubtedly been much broader than it is possible to document. The following pages therefore offer a representative sampling of examples of Earth benefits in life-sciences-related applications, primarily in the area of medicine and health care, but also in agricultural productivity, environmental monitoring and safety, and the environment.

This brochure is not intended as an exhaustive listing, but as an overview to acquaint the reader with the breadth of areas in which the space life sciences have, in one way or another, contributed a unique perspective to the solution of problems on Earth. Most of the examples cited were derived directly from space life sciences research and technology. Some examples resulted from other space technologies, but have found important life sciences applications on Earth. And, finally, we have included several areas in which Earth benefits are anticipated from biomedical and biological research conducted in support of future human exploration missions.

Arnauld E. Nicogossian, M.D.
Director, Life Sciences Division

An Exploration of Benefits from NASA "Spinoff."
Study conducted by Chapman Research Group, Inc.
National Aeronautics and Space Administration
Washington, DC, June 1989.

Introduction

"(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;"

From the National Aeronautics and Space Act of 1958.

The National Aeronautics and Space Administration (NASA) is committed to extending the benefits of its scientific and technological achievements and research beyond the direct needs of space missions, and applying the results of Agency programs, wherever possible, to the improvement of life on Earth.

Historically, the challenges associated with space flight have provided the impetus for strides in basic science and the accelerated development of advanced technologies. Perhaps the best known example is the revolution in computerization and miniaturization of technologies sparked by the Apollo Program. Integrated circuitry and its use in patient monitoring equipment may have been space technology's first application of importance to terrestrial medicine.

Over the past three decades many technologies originally developed for the space program have found important life sciences applications, which have contributed to the betterment of life for the ill, the disabled, the elderly, and the general population. Now, in the fourth decade of the U.S. space program, new benefits are anticipated from ongoing space life sciences

research on the Space Shuttle, and from the work to be done in the relatively near future to lay the scientific and technological foundation for future space missions.

Spinoffs from space research and technology can be separated into two major categories: direct and indirect. The direct spin-off is used for the same or a very similar application on Earth, with little or no modification. The specially developed electrodes and telemetry equipment used to monitor the hearts of the Mercury astronauts are examples. Indirect spin-offs are scientific findings or technologies that require modification for application in the same or similar discipline or field, while others are in some way usable in a totally unrelated application. In the former group is the liquid-cooled garment that was designed to be worn inside astronauts' pressure suits to control body temperature. With extensive modification the basic design is used in the medical setting, and in racing cars and military aircraft to prevent excessive body temperatures. An example of the second is found in the research on thermal proteins conducted by NASA's Exobiology Program. The use of the modified products of this research in terrestrial waste and pollution control is certainly an indirect application.

As the exploration of space proceeds, further benefits for medicine and health care on Earth are expected. Many of the characteristics of medical and life support systems for space exploration are equally valuable for terrestrial health care systems. Among these are further computerization and miniaturization, improved diagnostic imaging, greater automation, increasing ease of operation, and higher

reliability. Technologies developed for space missions may help streamline diagnostic procedures, patient monitoring, and other health care functions in busy urban hospitals and medical facilities in remote or rural areas.

Space also affords a unique global perspective from which to examine our own planet. This will be a parallel activity with outward expansion into the solar system beginning in the late 1990s. Using satellite-based remote sensing technology, NASA's "Mission to Planet Earth" is being designed to document, understand, and predict global change. As part of the mission, the Life Sciences Division's Biospheric Research Program is dedicated to understanding how biological and planetary processes interact, and how, in conjunction with the environmental effects of human activity, these processes are affecting the long-term habitability of the Earth.

This question will be of increasing concern to future generations.

In order to take full advantage of the opportunities for clinical applications of scientific discoveries and new technologies from the space program, NASA established the Technology Applications Teams at several university centers. The primary mission of these teams in the life sciences area is to facilitate the development of solutions to medical and surgical problems using findings and technological breakthroughs from NASA programs.

Educational programs are an important means of assuring that NASA's efforts toward space exploration are of maximum benefit to life on Earth. In this case, the benefit resides in the training of the next generation of scientists and engineers. A science curriculum supplement

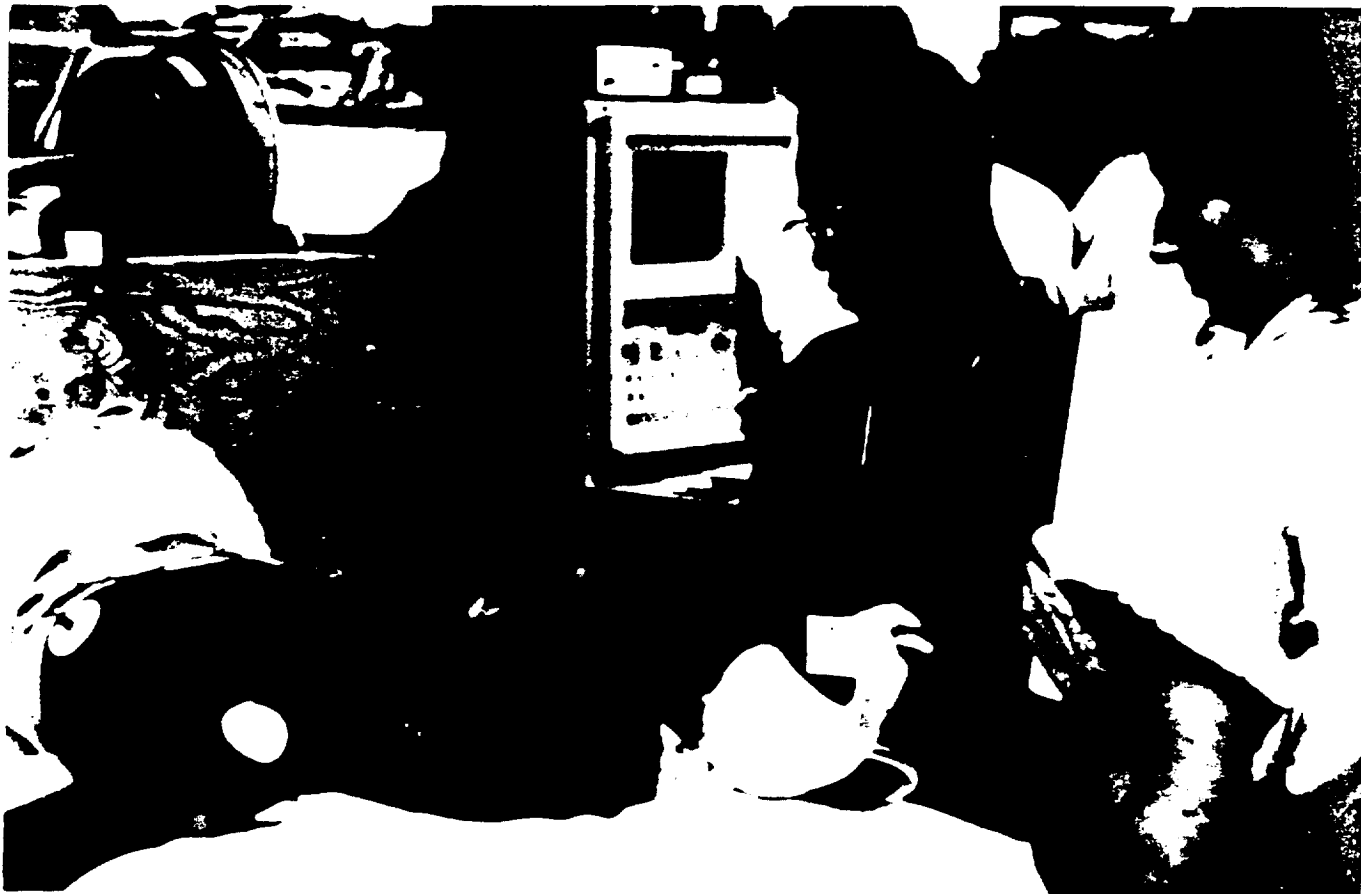


Figure 1. Part of the next generation of scientists and engineers. SLSTP students perform an experiment studying the effects of lower body negative pressure on the human cardiovascular system.

ORIGINAL PAGE IS
OF POOR QUALITY

entitled, "Human Physiology in Space: A Program for America" represents one of the NASA Life Sciences Division's contributions to the strengthening of the scientific base of the U.S. educational system. The supplement is intended for teachers and students at the secondary school level. The program, also sponsored in part by the National Institutes of Health, presents certain elements of human physiology from the new perspective provided by the emerging fields of space physiology and space biology. It is hoped that this approach of linking physiology education to space research will motivate students to study and master certain difficult concepts in human physiology.

1991 marked the seventh year of the Space Life Sciences Training Program (SLSTP) (Figure 1). This is a 6-week summer training course held at NASA's Kennedy Space Center and managed jointly by the Bionetics Corporation and Florida A&M University's College of Pharmacy and Pharmaceutical Sciences. Participants earn five semester hours, tuition-free. The goal is to introduce undergraduate students to the challenges and complexities of the real world of space flight through "hands-on" training of a new generation of space scientists and engineers. The program augments laboratory experience with lectures by astronauts and national and international leaders in the space life sciences.

Under the auspices of the Search for Extraterrestrial Intelligence (SETI) Program and in conjunction with the National Science Foundation, curriculum materials are being developed by an interdisciplinary team of teachers, educational specialists, and scientists from the NASA Ames Research Center, the Jet Propulsion Laboratory, and the SETI Institute. The goals are to bolster student interest in science and math at an age when this interest often wanes, foster critical thinking, acquaint students with the process of scientific investigation, and, ultimately, promote interest in scientific careers.

One of the goals of NASA, as stated in the United States National Space Policy (November 2, 1989), is, "to obtain scientific, technological and economic benefits for the general population and to improve the quality of life on Earth through space-related activities." This is a clear and explicit statement of the mission implied in the National Aeronautics and Space Act of 1958, quoted above. Over the years, our commitment to the spirit of the 1958 statement has placed us in an ideal posture to pursue the goal enunciated in the policy of 1989. And so, for the "benefit of all mankind," our programs continue.

Life Sciences Applications: Medicine and Health Care

Historical note on the space life sciences in NASA. In support of the first manned U.S. space missions, NASA life sciences programs in medicine and health care were initially directed at determining whether humans could withstand weightlessness and the rigors of launch and re-entry into Earth's gravity. The success of the Mercury and Gemini programs amply demonstrated that humans could not only survive, but work productively in space, and space life scientists turned their attention to more thoroughly characterizing the physiological changes that appear in virtually every body system after entry into weightlessness. These physiological changes (termed "space-flight deconditioning") can have potentially harmful health effects if not limited by countermeasures.

Skylab, the United States' first Earth-orbiting laboratory, provided the first opportunity for sustained biomedical research in space. Medical programs in NASA throughout the 1960s and 1970s focused on monitoring the health of astronauts before, during and after space flight, still a major role of NASA's Life Sciences Division. In the 1990s the Space Shuttle's Spacelab continues to provide regular access to Earth orbit for focused studies on human adaptation to space. In the near future, space life sciences research on Space Station Freedom will be directed in part at developing the physiological countermeasures necessary for lengthy future missions, which will require astronauts to spend increasingly longer periods in weightlessness. Basic scientific research in the space life sciences will continue to examine the relationship between gravity and life.

The progress of medical science over the last 50 years has extended the average individual's life-span well into middle age. This fortunate outcome, however, has also brought a higher incidence of age-related disease. The insidious nature of most age-related conditions results in delayed diagnosis with a high degree of morbidity and incapacitation. Timely intervention through early diagnosis of individuals at risk can save or extend lives, and reduce the costs associated with chronic conditions.

Most diseases are diagnosed when patients seek medical attention for specific symptoms, with only a few cases detected through annual screening. Certain technologies developed for the space program can be effectively applied to the development of rapid, low-cost, easy-to-use screening techniques that can be utilized in the course of routine surveillance, and over the years NASA technology has contributed to the management of chronic disease. One significant example is arteriosclerotic disease of the heart and blood vessels, which is the leading cause of death in the United States. Taking a broader view, technologies developed initially for space (e.g., telemetry, automated fluid handling, imagery, and miniaturization) have already enhanced conventional medical capabilities and opened new windows into the human body, while other new technologies are being tested and refined. This section provides examples that demonstrate the contributions of NASA technology to medicine and health care. Table 1 lists additional life sciences applications of space research and technology.

**Table 1. Past Life Sciences Applications of Space Research and Technology:
Medicine and Health Care***

This table lists prominent examples of spinoffs whose existence is due in whole or in part to NASA research, technology, consultation, materials, or techniques.

- **Dental arch wire material** with greater elasticity than stainless steel wire
- **Cardiology mannequin** that simulates 40 heart disease conditions for medical education
- Implantable **human tissue stimulator** provides electro-stimulation of tissue for pain relief and other applications
- **Electrode-based electrolyte analyzers**
- **Aseptic fluid transfer system** that allows the transfer of fluids between containers in a sterile manner
- **Automated light microscopy** for chromosome analysis and karyotyping
- Automated, computer-aided system for **muscle tissue analysis**
- **Eye movement tracking device** that incorporates laser technology used in laser retinal surgery
- **Biotelemetry system for gait analysis** in cerebral palsy patients
- **Ocular screening system** for detecting visual abnormalities
- Wearable **speech perception aid** for the deaf
- **Biotelemetry package for hip replacement implant**
- Sensitive technique for recording and analyzing human respiratory sounds, to aid in **non-invasive lung diagnosis**
- **UNISTIK driving device** increases mobility for handicapped drivers
- **ATP photometer** enables a rapid and accurate count of bacteria in body fluid samples
- One-step **liquid-liquid extraction technique** for separating chemical compounds in body fluid samples
- **FMLOS computer program for analyzing biological substances**
- **Portable Medical Status and Treatment System** for use by paramedics in remote areas
- **Medical gas analyzer** assists in anesthesiology
- **Heart rate monitor**
- **Bone stiffness analyzer** used in the diagnosis of early osteoporosis
- Digital image processing technology used in the **evaluation of skin care products**
- **System for precise evaluation of posture and balance disturbances**—quantitative diagnostic system for neurological and musculoskeletal disorders
- **Ingestible Thermal Monitoring System**—a capsule swallowed by the patient, which monitors body temperature as it passes through the body
- **Self-Injurious Behavior Inhibiting System (SIBIS)** helps retarded and autistic patients avoid self-destructive behaviors
- **Thermal video system** for heat detection, used in diagnosis of burns and breast cancer
- **Programmable Remapper** image processing machine for aiding the visually impaired
- **Biofeedback system for improving vision**
- **Computer reader for the blind**
- **Sterilization system** for medical instruments

* Further information about these and other spinoffs in medicine and health care may be found in the documents listed in the Bibliography.

Biotelemetry

Biotelemetry is a method whereby physiological data are converted into signals which are then sent to monitoring personnel at remote locations. It is now used routinely for monitoring patients in hospitals, ambulances, or small clinics. Biotelemetry also permits physicians to communicate with or program implanted instruments, such as pacemakers or medication delivery systems. NASA was a pioneer in biotelemetry. It was recognized in the earliest days of Project Mercury that it was necessary to monitor the heart and respiration of the astronauts who began our odyssey into space. While the techniques for recording electrocardiograms were well known, methods to transmit these streams of data over great distances were at best clumsy, unstable, and too large in weight and volume. It was also necessary to overcome the problems of vibration and radio frequency interference in order to provide a reliable system for monitoring astronauts in space flight. The work of NASA and contractor scientists and technicians brought about the miniaturization of the equipment, improvements in the character of the signal, and new surface electrodes that permitted long periods of wear without damage to the skin. In a sense, this requirement for the monitoring of human health in space brought about a quantum jump in the science and technology of biotelemetry.

The value of biotelemetry on Earth has been demonstrated repeatedly, but perhaps the most dramatic was during the STARPAHC Project (Space Technology Applied to Rural Papago Health Care), where medical data of patients in the remote Papago Indian Reservation in Arizona were transmitted, via a communications network, from a mobile clinic to a distant base of operations. At this base, physicians monitored the data, made diagnoses, and prescribed treatments.

Medical Imaging

Imaging instruments and digital image processing techniques developed for the space program have contributed to improvements in the diagnosis of health problems on Earth. The well known "CAT" scan, whose high-resolution images revolutionized diagnostic imaging, is based on digital image analysis techniques developed by NASA's Jet Propulsion Laboratory to analyze images of the planets. The CAT scan (now referred to as computed tomography or CT) reconstructs, with the aid of computers, a tomographic (slice-like) image from the multiple views obtained by a fan-shaped X-ray beam. CT is now routinely used for diagnosis in most hospitals and medical centers.

Magnetic resonance imaging (MRI) hardware has been in existence for decades, but it is only in recent years that it has been used regularly for medical diagnosis. Space image processing techniques have greatly improved the quality of



Figure 2. Sagittal view of the head, obtained with MRI imagery.



Figure 3. The Lixiscope utilizes a weak radiation source to help physicians diagnose bone injuries, among other conditions.

MRI images. MRI also allows physicians to view, without exposing the patient to x-rays, cross sections of the internal organs, using a magnetic field and radio waves to create body images for diagnostic purposes (Figure 2). Able to penetrate bone (which blocks conventional x-rays), MRI is sensitive to soft tissues like the kidney and liver. CT and MRI complement one another in that each is particularly useful for viewing certain organs of the body. A computer program (HICAP), developed by NASA for distinguishing terrestrial surface features in satellite imagery, is being used by researchers at the Department of Radiology at the University of Michigan Hospital in Ann Arbor in an effort to combine the best features of MRI and CT scans.

A device developed by NASA and called the Lixiscope (using low-intensity x-ray imaging techniques for the study of celestial objects) utilizes a weak radiation source that reduces the radiation dose to less than one-percent of that generated by conventional x-ray devices (Figure 3). Compact and portable, the system can be used in the homes of bedridden and handi-

capped patients, and is ideal for emergency use in field situations (for example, scanning for bone injuries in accidents). Other uses include dental examinations and orthopedic surgery, and rapid, non-destructive testing for industrial purposes.

Help for Cardiac Patients

Preventive Screening and Monitoring

Spinoff technologies from the U.S. space program have contributed to the increasing public emphasis on prevention of heart disease and other health problems. Hypertension, or elevated blood pressure, is basically a "silent disease" due to its insidious nature prior to detection. For years, easy-to-use blood pressure screening devices based on Apollo/Skylab technology have been widely located in public places, providing opportunities for early detection of disease by the many who are not aware of their problem. This type of system allows the hypertension sufferer to monitor blood pressure between visits to the doctor's office.

A portable, computerized system developed from space technology offers a new approach for monitoring ambulatory heart patients. The key to the system was the electrode—it had to last for long periods, provide high fidelity, and avoid constant skin abrasion. The monitor alerts the patient to impending high-risk heart events by continuously evaluating the heart's electrical signals and making immediate "decisions" as to normalcy. The device may be attached to the patient's garment or carried in a pocket. Its computer record allows a physician to track a patient's progress, evaluate drug treatment, and adjust dosage.

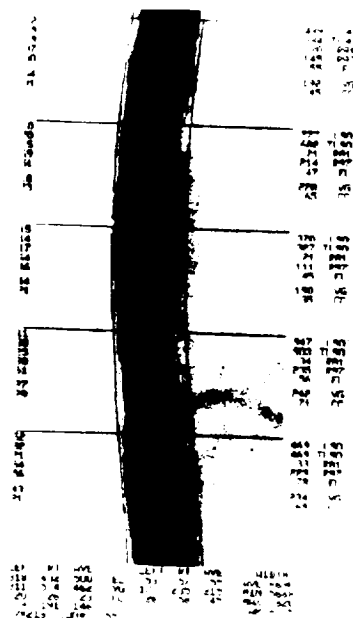


Figure 4. This technician is using computer-aided imaging techniques developed at NASA's Jet Propulsion Laboratory to measure the extent of atherosclerotic lesions. The photograph at right shows the detail of the image obtained.

Diagnosis

About one-half of all deaths in this country may be attributed, directly or indirectly, to cardiovascular abnormalities. Furthermore, in recent years, autopsy studies have revealed that most American males beyond the age of 30 have developed some degree of atherosclerosis, which is a progressive buildup of fatty and calcified deposits within arteries, resulting in obstructed blood flow and increased blood pressure. As a diagnostic tool, ultrasound employs very-high-frequency sound waves to visualize internal body structures. Ultrasound is used in the diagnosis of atherosclerosis. To generate a three-dimensional image of an artery, ultrasound pictures are obtained at intervals along an artery and computer techniques are applied to locate the boundary of the vessel in each cross section. The three-dimensional image can then help physicians assess the need for surgical intervention.

Intent on improving the use of ultrasound as a diagnostic tool in medicine, NASA scientists worked for a decade to develop an ultrasonic

instrument for non-invasive imaging—the Ultrasonic Time-Delay Spectrometer Scanner (TDS)—that could transmit a pulse and “listen” for a simultaneous return from the target. This was an improvement over the conventional pulse-echo, or “on-off,” method used by previous ultrasound diagnostic instruments, which had been the major limitation of the technology. The TDS produced images with higher resolution and a better signal-to-noise ratio. With the improvements brought about by NASA's work, ultrasonic scanning now complements other medical imaging technologies, such as computed tomography (CT) and magnetic resonance imaging (MRI).

NASA Jet Propulsion Laboratory (JPL) scientists have developed and clinically tested a computer-aided image analysis method to detect and measure atherosclerotic lesions revealed by angiograms. This technique utilizes an image analysis method originally developed for analyzing images of the planets. The value of this technique resides in its accuracy and capacity for making long-term comparisons, and it is expected to come into increasingly

wider use in the fight against coronary artery disease (Figure 4).

Devices for Treating Cardiovascular Disease

Death rates from hypertension can be greatly reduced through a continuous and intensive drug treatment program. Yet patients, especially children, often have difficulty maintaining a program of oral medication: Since hypertension in itself has no symptoms, individuals may feel no particular urgency to take the medication. An implantable device, the Sensor-Actuated Medication System (SAMS) improves the control of hypertension through the continuous administration of medication. The device releases anti-hypertensive medications in accordance with signals from a blood pressure sensing component. It incorporates microminaturized circuitry and programming technology used on NASA's Small Astronomy Satellite and

other spacecraft. Clinical trials are also investigating whether the SAMS can be modified to control hypertension through biofeedback, a type of self-regulation in which one learns to control biological activity normally beyond voluntary control. The modification permits the System for Measurement and Control of Hypertension (SYMCOH) to sense blood pressure and sound an alarm signal that triggers the biofeedback response.

Many fatal heart attacks result from malfunction of the heart's conduction system. With early diagnosis, a pacemaker can be implanted to generate an electrical pulse that controls heart contractions. A programmable pacemaker with a two-way communications capability was developed in 1979, a spinoff from space technology (Figure 5). This capability allows physicians to remotely monitor and interact with the pacemaker. Where earlier implantable pacemakers delivered a fixed stimulus, this system can be "fine-tuned" without surgery in accordance with the individual needs of patients, which may change over time. This lessens the length of time patients must remain in the hospital after implantation, and their cardiac activity can be monitored throughout their normal daily routine. An advanced pacer that closely matches the heart's natural rhythm is currently available, with an activity sensor that responds to body movement. The device features 28 pacing functions and thousands of programming combinations to accommodate diverse life-styles and a range of activities. The pacemaker system won Food and Drug Administration approval for general marketing in 1989 after clinical trials involving more than 750 implants in more than 90 hospitals.

Over 1 million Americans suffer heart attacks annually, with approximately 50,000 dying after 1 year, mostly from ventricular fibrillation, a catastrophic disruption of the normal heart rhythm. An Automatic Implantable Defibrillator was developed through NASA-sponsored

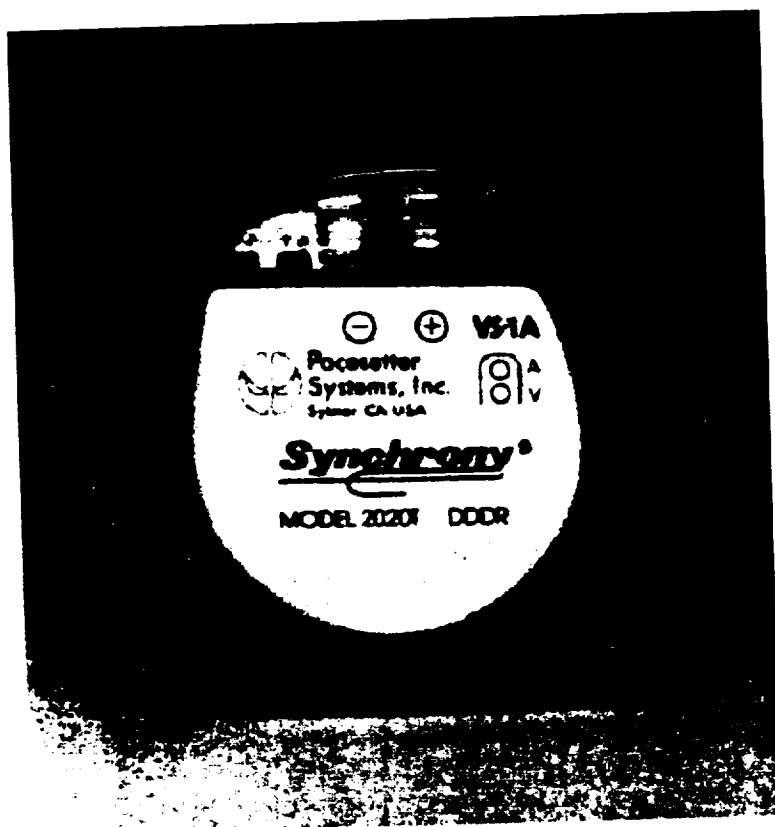


Figure 5. This pacemaker, derived from space technology, has dramatically expanded the range of activities available to cardiac patients.

research for use by high-risk patients. When this apparatus detects the onset of irregularities in heart rhythm, it automatically delivers an electric impulse to restore normal rhythmic activity.

Lightweight and easy to handle, the Advanced Portable Defibrillator, another space technology spinoff, is used to revive heart attack victims (Figure 6). The defibrillator sends an electric shock to the heart via two metal paddles placed on the chest wall, terminating the abnormal rhythms and allowing the heart to return to a normal pace. Telemetry can be added for remote monitoring of victims in the field by hospital-based medical personnel.

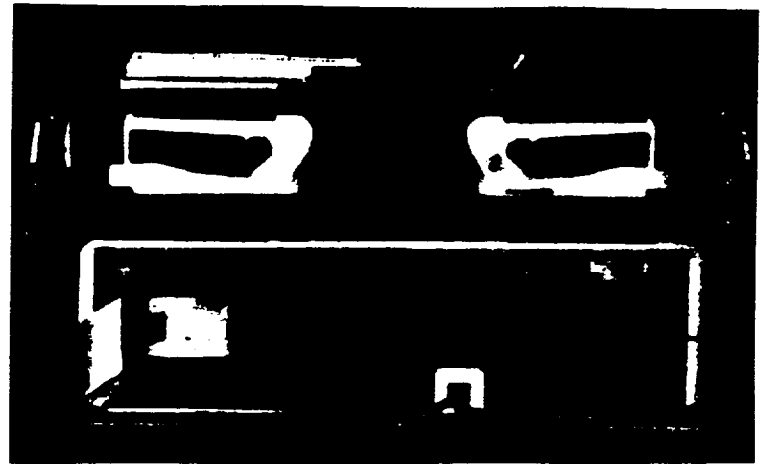


Figure 6. Immediate restoration of heartbeat using devices such as the Advanced Portable Defibrillator increases the chances of survival after cardiac arrest.

The excimer (for excited dimer) xenon chloride laser was originally designed by NASA to measure atmospheric ozone. The excimer laser caught the interest of physicians searching for a technique to deliver a laser beam through fiber optic filaments to eliminate plaque deposits from the lining of coronary blood vessels without burning the vessel. The excimer laser allows physicians to see inside a blood vessel without first cutting it open. An extremely small catheter is threaded into the arteries of the heart. Within it, tiny and flexible glass fibers encircle a highly miniaturized lens connected to an external

camera which is in turn connected to a monitor. This configuration allows the physician to follow the progress of the catheter tip. The excimer pinpoints and destroys tiny areas of plaque with short energy bursts at unusually low temperatures, avoiding burns to normal tissue.

The Baro-Cuff (Figure 7) was originally developed to study blood pressure reflex controls in space. Reduced in complexity, it was adapted for the study of cardiovascular physiology on Earth. The system is now available commercially as a tool for the study of blood pressure

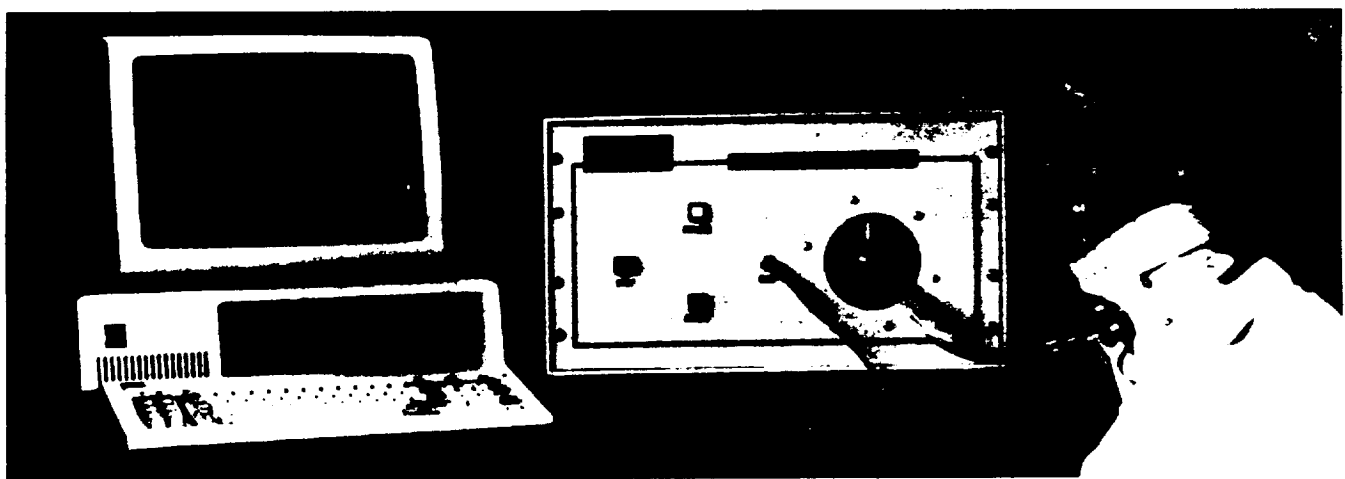


Figure 7. Originally developed for use in space, the Baro-Cuff is now available commercially as a clinical tool for the study of blood pressure controls.

ORIGINAL SOURCE
OF POOR QUALITY

controls in patients with congestive heart failure, chronic diabetes mellitus, hypertension, or other conditions that involve abnormal blood pressure control. It is also used in kidney function research. The Baro-Cuff is a silicone rubber chamber that is placed around the patient's neck. It stimulates blood pressure controls in the carotid arteries by electronically controlled application of pressure or suction.

Medication Delivery

It is estimated that one million insulin-dependent diabetics in the United States will benefit from implantable infusion systems that alleviate the need for daily injection with the insulin hormone. The highly miniaturized fluid controls used for metering nutrients into the Mars soil samples collected by the Viking lander provided the basic design for the Programmable Implantable Medication System (PIMS) pump (Figure 8), which is capable of metering medication in precise doses. Amenable to individual lifestyles, the PIMS allows the patient to perform limited monitoring and reprogramming to adjust for changes in daily routine.

Cancer Therapy

In the latter half of the 1970s NASA Lewis Research Center's Cyclotron Facility, in a collaborative agreement between NASA and the Cleveland Clinic Foundation, was dedicated to an experimental program testing the efficacy of fast-neutron therapy for cancer treatment. The Cyclotron was the first facility to provide both horizontal and vertical beams, an advantage that allowed a greater range of tumors to be targeted for radiation therapy (previously only horizontal beams were used, which made it difficult to target certain organs and areas of the body). NASA contributed both personnel and materials to the program. Patients were treated on a regular basis according to protocols prepared by a national group dedicated to the study and treatment of tumors (the Radiation



Figure 8. Robert E. Fischell of the Johns Hopkins University Applied Physics Laboratory, who headed the initial development of the PIMS as a technology utilization project, shows the PIMS with its cover removed. The PIMS holds about two and one-half teaspoons of insulin at a programmed basal rate.

Therapy Oncology Group). The data gathered at the Cyclotron made it possible to determine that fast-neutron therapy was particularly effective in treating salivary gland, head and neck, and prostate tumors.

Sample Analysis

An automated system based on Voyager technology is used for the analysis of body fluid samples in hospital laboratories to identify microorganisms that cause infection and to test effective treatments. The AutoMicrobic System[®] (AMS) (Figure 9) originated from a NASA-sponsored study aimed at developing a fully automated microbial detection and identification system for the space program. The AMS

AutoMicrobic System and AMS are registered trademarks of McDonnell Douglas Corporation.



Figure 9. The miniaturized version of the AutoMicrobic System (foreground), with the original version in the background.

allows a laboratory to furnish more accurate guidelines for antimicrobial therapy the day after a specimen is collected (a time saving of 50 to 80 percent over standard methods), leading to swifter analyses, increased accuracy, earlier treatment, and shortened hospital stays. A state-of-the-art, miniaturized version of the AMS is being developed to enable rapid identification of infectious microbes on Space Station Freedom.

Accurate blood analysis requires a determination of the presence and amount of specific blood constituents without interference from other compounds in the mixture. Electrophoresis is a process that separates the components of a fluid through the use of an electric current. A commercially available electrophoresis system based on a device originally developed for use in weightlessness allows the rapid separation, identification, and quantification of specific

blood proteins in very small quantities. The Grunbaum System for Electrophoresis (named after the investigator who developed the original device) can handle up to 20 samples simultaneously, and has found broad utility in medical research and diagnosis. Able to analyze substances other than blood, this device is used in agriculture, pharmaceuticals, and other industries.

Personal Cooling Systems

Cool suits—liquid-cooled garments based on NASA space-suit and protective systems technology—have expanded the range of activities available to children in the United States and other countries who have been born without sweat glands, or suffer personal heating disorders. The garments are also used in medical research programs, including studies of body temperature control in cancer therapy, and cooling during surgery. Variations of the garment have helped quadriplegics, who are often unable to tolerate heat stress because of an inability to perspire below the waist. Space-suit and protective systems technology from the Apollo, Skylab, and Space Shuttle programs (Figure 10) was also incorporated in the early 1980s into a lightweight cooling vest produced by a private firm for use in industrial settings where workers are exposed to high temperatures.



Figure 10. Liquid-cooled garments based on protective systems technology are improving the quality of life for patients with personal heating disorders.

Earth Benefits from Space Life Sciences Research and Technology:

From the Present to the Future

An Improved Understanding of Health and Disease on Earth

Research conducted on the Space Shuttle, Space Station Freedom, and in laboratories on Earth, to prepare humans for long missions in space, will lead to a greater understanding of health and disease on Earth. Integrated studies of the body's response to weightlessness will further elucidate the complex interactions among physiological systems in normal gravity. Studies seeking to more thoroughly describe and, ultimately, counter any undesirable effects

of weightlessness on a range of body systems will improve our knowledge of disease processes in general. For example, investigations of the function of the heart and lungs after exposure to weightlessness could lead to a better understanding of the mechanisms causing orthostatic (postural) hypotension and cardiovascular arrhythmias, possibly yielding improved treatments. Therapies for immunosuppressed patients on Earth might arise from studies of the effects of space flight on the immune system, while countermeasures to muscle and bone atrophy in space could

further our knowledge of musculoskeletal diseases and contribute to novel therapies, possibly including new exercise therapies.

In addition, studies of human behavior and performance on Space Station Freedom could contribute to the field of preventive psychiatry, particularly in assisting those who must work for long periods in isolated and/or confined or hazardous environments.

Possible Treatments for Osteoporosis

Some 25 million Americans are affected by osteoporosis, or bone loss, a common malady in post-menopausal women (Figure 11) and elderly men, which often results in brittle, porous bones, which are more easily broken. It is estimated that osteoporosis leads to 1.3 million fractures annually. By 2020, costs associated with this problem are expected to rise to \$30-60 billion per year without new preventive measures and treatments.* Yet the human costs of osteoporosis are equally compelling: the pain of fractures and the discomfort of lengthy rehabilitation, the limitations imposed on the lifestyle of senior citizens, the psychological residue of fear that follows a fall or other accident.

One of the health hazards of long-term space flight is bone loss induced by the absence of gravity loading of the skeletal system. This loss bears certain similarities to the osteoporosis of aging. Space life sciences research targeted at determining the mechanisms of bone loss in space could help in the search for a cure for osteoporosis, while exercise countermeasures and pharmaceuticals (e.g., fluoride, diphosphonates) for use in space may yield better treatments and slow the progress of osteoporosis in patients on Earth. Countermeasures for the loss of bone mineral in space may, in addition, lead to effective measures for the prevention of kidney stones on Earth.

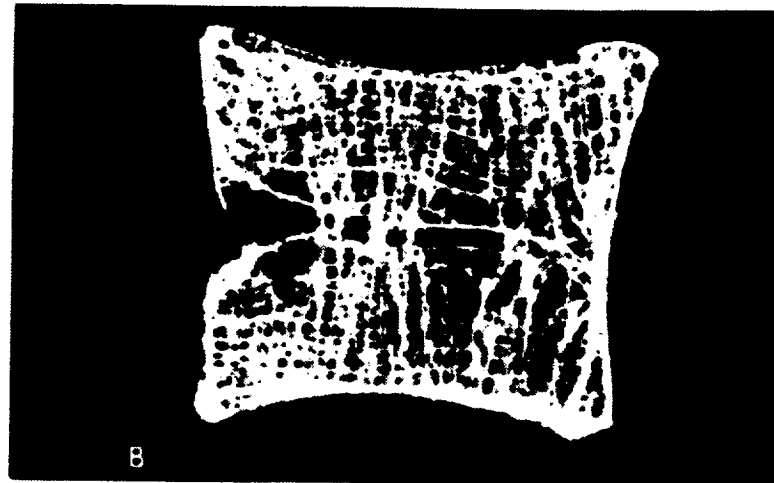
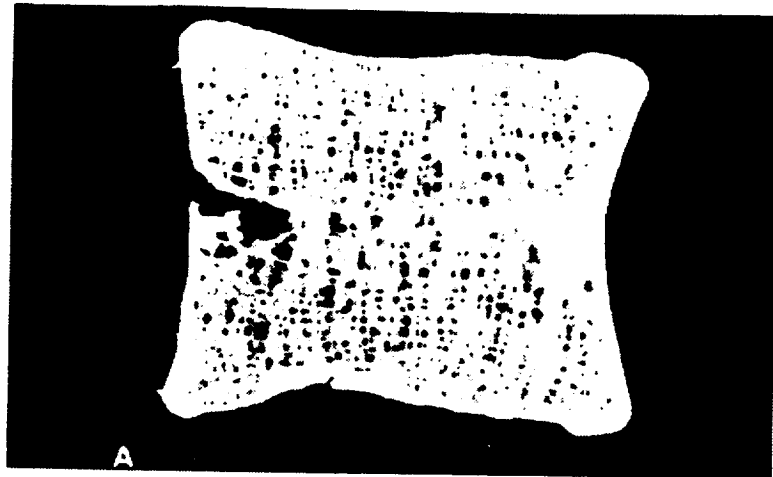


Figure 11. At top is normal bone. At bottom is osteoporotic bone from the vertebral body of the spine.

NASA has also been at the forefront in the promotion of clinical technology to measure bone mass loss. Bone densitometry, a technique originally developed by NASA, offers significant advantages over standard x-rays in determining bone density, improving the precision of measurement to less than a 1-percent error rate, and allowing accurate clinical judgments.

Artificial Gravity and Neurophysiology

The U.S. Congress has designated the 1990s "The Decade of the Brain." NASA, along with other government agencies and institutes, will be undertaking research aimed at a more

* *Boning Up on Osteoporosis: A Guide to Prevention and Treatment.* Copyright 1989. National Osteoporosis Foundation. Washington, DC.

complete understanding of the function of the human brain. Improved therapies for patients suffering from brain and spinal cord damage and other neurological disorders may be gleaned from studies of central nervous system (CNS) function during space flight.

Studies on the physiological effects of artificial gravity, particularly its effects on the human CNS, may find medical applications in neurophysiology and the treatment of disorders of the vestibular system (i.e., the structures in the inner ear that help to control posture, balance, and locomotion). Vestibular disorders can lead to falls, which in turn may have serious health consequences, particularly in the elderly.

People troubled by motion sickness on Earth have gained some relief through NASA research on the treatment of space motion sickness (SMS). The effectiveness of any drug depends on how much of it can be absorbed into the body, and some people experience problems taking medications orally (e.g., slow or incomplete absorption). New routes of administration for scopolamine, a drug that has been tested as a countermeasure to SMS, may avoid problems that sometimes occur when medications are taken orally. A scopolamine patch, created in a development effort partially funded by NASA, allows absorption of the drug through the skin. The patch is worn behind the ear.

Those who suffer from various forms of motion sickness may also find relief through a new form of scopolamine nasal drops, recently developed by NASA scientists. In addition, NASA scientists have devised an autogenic feedback training (AFT) procedure that uses biofeedback to prevent SMS. Studies are now planned to determine if AFT can be successfully applied to patients on Earth who suffer from nausea or vomiting induced by chemotherapy or other conditions.

Exercise and Rehabilitation

Astronauts exercise as a primary means of maintaining good physical condition in space. Special exercise equipment, suitable for use in microgravity, is being designed for portability and compactness (for use within the limited spacecraft area) and high efficiency (to allow maximum conditioning of several body systems at once). This combination of qualities should lead to advanced exercise hardware that can be used on Earth in the rehabilitation of bedridden patients. In addition, computer software under development to monitor fitness trends in Space Station Freedom crews will provide significant advances in exercise science, which may benefit rehabilitative medicine, the fitness industry, and competitive athletes.

In NASA-sponsored work at Pennsylvania State, researchers are using a device that simulates

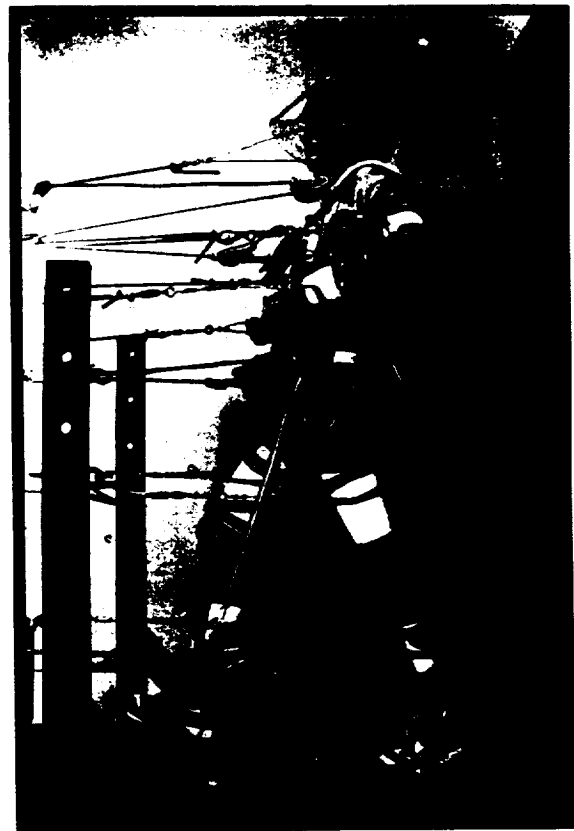


Figure 12. Devices such as the zero-gravity locomotion simulator could help to safely retrain bedridden or other patients who must re-learn the coordination required for walking.

locomotion in zero-gravity to study the biomechanics of exercise in space, with the aim of using high impact exercise to help prevent space-flight-induced bone loss (Figure 12). A patient using this device could re-learn the coordination required for walking, without the risk of falling and without bearing excessive loads on the skeleton and joints. In previous years, a lunar gravity simulator was used to train physically and mentally incapacitated children to walk.

Radiation Health

The development of strategies to protect astronauts from the radiation hazards of space beyond Earth's protective magnetic field may produce a better understanding of the biological effects of radiation on Earth, particularly in the area of cancer induction. Furthermore, the use of microgravity as a unique laboratory tool on Space Station Freedom should help unlock the secrets of tumor cells, contributing to the ongoing effort to find a cure for this disease. Studies of space radiation—and the development of protective countermeasures—could lead to better long-term occupational health strategies for workers in jobs associated with high radiation levels. Additional benefits for occupational medicine could include improved radioprotectants and radiation detection capabilities, and enhanced diagnosis of radiation-related health problems. Among the research approaches being considered by NASA are pharmaceuticals and activation of cellular repair mechanisms.

Medical Equipment

The Crew Health Care System (CHeCS) is currently under development to support medical care on Space Station Freedom. Integrated and compact, the CHeCS has been designed to provide medical, minor surgical and dental care in the limited area available on the station. A subsystem of the CHeCS, the Health Maintenance Facility (HMF), will require extensive

miniaturization of components, including laboratory, x-ray, and other diagnostic equipment. Miniaturization of medical technology will prove particularly valuable for field hospitals and remote medical care. Many of the HMF's capabilities hold promise for use in analogous settings on Earth, including bioisolation, environmental sampling in closed systems, computerized medical protocols, telemedicine, vital-sign monitoring, and life support for ambulances. The HMF prep tent shown in Figure 13 can be utilized for a variety of tasks in support of medical operations.

ORIGINAL PAGE IS
OF POOR QUALITY



Figure 13. Health Maintenance Facility (HMF) prep tent. Designed for crew health care on Space Station Freedom, the HMF's array of capabilities should prove helpful in such terrestrial settings as field hospitals.

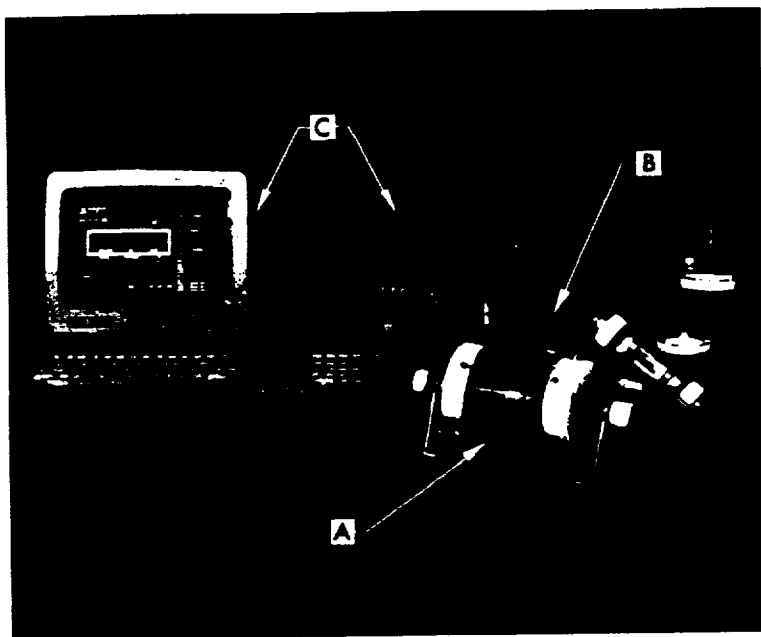


Figure 14. The primary components of the Rotating Wall Perfused Bioreactor are (A) a rotating culture vessel, (B) an external media perfusion loop with associated environmental control effectors, and (C) a computerized process-control system. The Bioreactor presents exciting possibilities for biotechnology.

Biotechnology

Results from NASA research aimed at furthering our understanding of the origin of life may find applications in neurobiology and neuromedicine. Some of the proteins obtained in laboratory experiments retracing evolution have demonstrated anti-aging effects for rat brain neurons in culture, along with properties of nerve regeneration. This work could lead to various medical benefits, including anti-aging in general, and the production of synthetic nerve growth factors, which could help in the repair of severed nerves. Related thermal proteins formed in the laboratory have shown promise as memory enhancers, opening the way towards the development of memory enhancing agents that might be delivered orally to humans to treat disorders like Alzheimer's Disease.

The Rotating-Wall Perfused Bioreactor (Figure 14), developed by scientists in NASA's Space Biotechnology Program, allows the growth of human tissue in a cell culture system that

emulates the microgravity of space. Cells are placed in a rotating vessel in the bioreactor, and segments of body parts are grown to the size of a few millimeters after exposure to varying levels of gravity. Researchers have already modeled human small intestine, and tumor tissue cultured in the bioreactor has in many respects proved indistinguishable from tissue obtained from patients. While this research is currently in the beginning stages, such medical applications may be foreseen as the growth of tissue for transplantation, cancer and antiviral therapies, models for drug testing, and the study of disease processes in human tissue.

New biochemical sensors—very tiny instruments that can easily be implanted or inserted into the body—are being developed at NASA to measure concentrations of ions such as calcium, sodium, and potassium, in space or on Earth. In 1989, NASA Ames Research Center entered into a joint agreement with private-sector partners to develop an implantable calcium ion sensor. This new sensor will enable rapid and accurate blood analysis, which will facilitate the treatment of certain diseases, such as parathyroid disorders, which can be difficult to diagnose. Potential public health applications include the on-site analysis of drinking water or waste water.

Telemedicine

Telemedicine holds great promise for improving health care in urban and remote rural areas by providing direct satellite links between paramedic personnel working with the patient and physicians at a central or multiple locations. Slow-scan telemedicine, which originated in the space program and is now used across the United States and in other countries, permits the rapid transmission of still video images inexpensively over telephone lines, radio, microwave and satellite channels. Physicians and medical specialists at widely separated sites can have

simultaneous access, in real time, to computed tomography (CT) scans, x-rays, and other diagnostic information. The resulting time savings could save lives, particularly in emergencies.

The U.S.-U.S.S.R. Telemedicine Spacebridge provides a dramatic example of the efficacy of telemedicine in addressing terrestrial disasters. In December 1988, after an earthquake devastated Soviet Armenia, NASA presented the Soviet government with an official offer of telecommunications assistance to establish a means to relay U.S. medical advice via satellite to doctors in Armenia. The Telemedicine Spacebridge was subsequently established as a cooperative endeavor under the auspices of the U.S.-U.S.S.R. Joint Working Group on Space Biology and Medicine.

Linked by satellite network, the doctors using the Spacebridge had simultaneous access to audio, visual, and fax communications originating from sites in both the United States and the U.S.S.R. (Figure 15). Sometimes with the patient on hand, Armenian doctors presented patient data to their colleagues at U.S. medical centers, who then made recommendations for treatment or further study. Other consultations focused on public health issues, such as sanitation problems and the potential spread of disease. After a railway accident in May 1989 outside the Soviet city of Ufa in the Ural Mountains, Spacebridge links were extended to Moscow and Ufa to provide access to U.S. medical expertise, especially in the field of burn treatment. Over 400 physicians and medical personnel from both countries participated in 51 consultations during the existence of the Spacebridge.

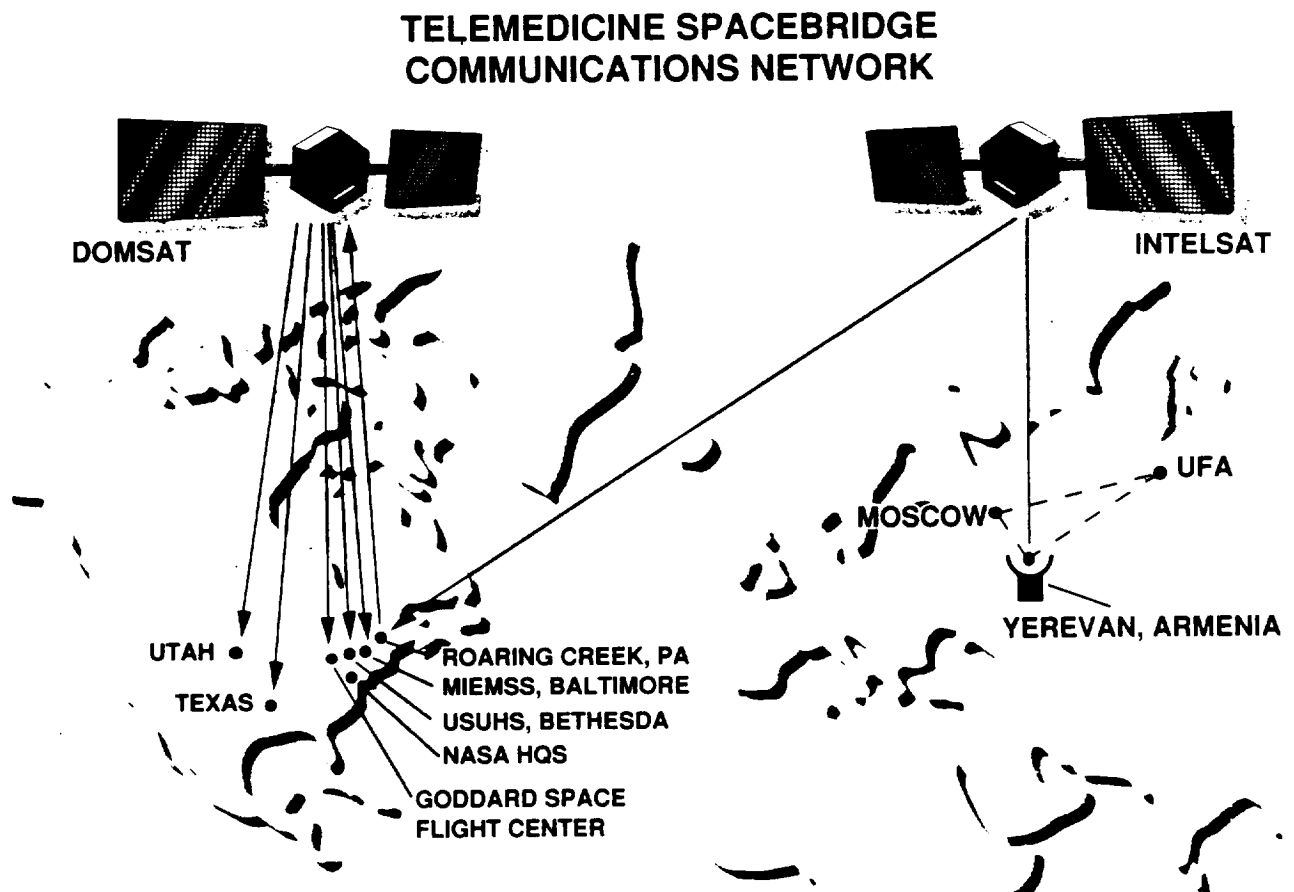


Figure 15. Telemedicine Spacebridge.

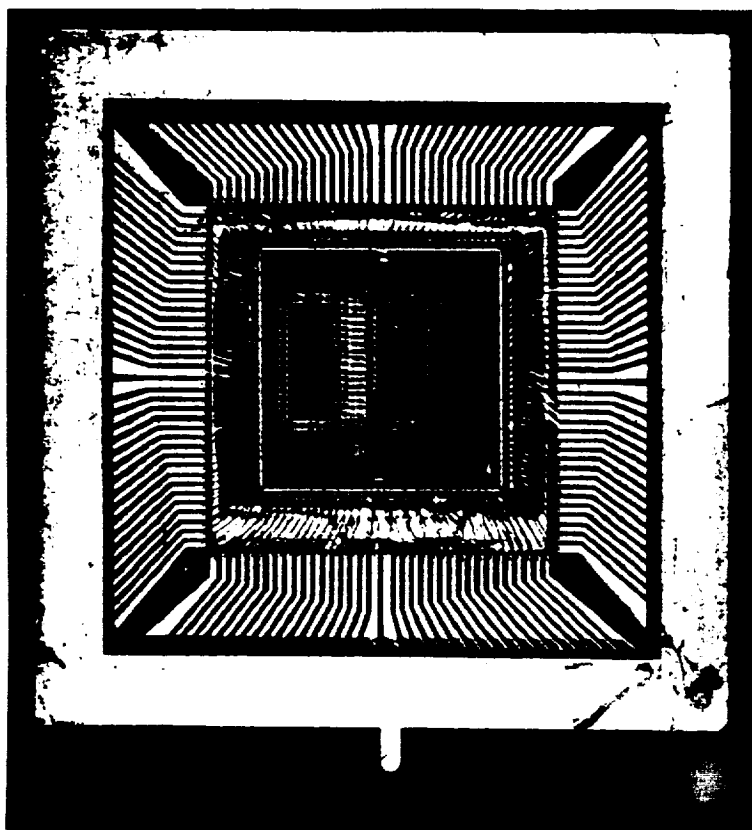


Figure 16. The SETI digital signal processor chip from the Multi-Channel Spectrum Analyzer is only 8 mm square and contains the equivalent of 34,000 transistors.

Diagnostic Assistance

Crewmembers on future space missions will need immediate and thorough access to information on any medical problems that could arise. To meet this challenge, biomedical researchers at Kennedy Space Center (KSC) and the University of Florida have developed an interactive computer program, Clinical Practice Library of Medicine (CPLM). The program, which is in use at KSC, allows the user to simultaneously search multiple standard medical texts, such as Merck's Diagnostic Manual, for key words. Signs, symptoms, and conditions may be qualified to obtain specific diagnoses, therapies, or treatment protocols.

CPLM will provide space crewmembers who have varying levels of medical knowledge and skill a tool for swift and accurate diagnosis and treatment, especially valuable for secondary

and tertiary treatment of an acute event. CPLM offers the same advantages on Earth as in space, with additional possibilities for medical education. The program is ideal for emergency care in settings where medical capabilities are limited—in remote polar stations, for example, and submarines.

Projecting further into the future, crew physicians will use computer-aided medical diagnosis systems on Mars journeys, which could last up to 3 years. Similar systems have been in development for several decades, but have not yet gained widespread clinical use. NASA's requirement for such a system results from the long delays in radio communication over interplanetary distances (around 40 minutes round-trip for communication with Mars). Computer-aided diagnosis would provide, in effect, a "second opinion," or reference source for the crew physician. A refined version of this system would be useful as a clinical and/or teaching tool, and could help contain medical costs by extending the efficacy of paramedic personnel.

Computerization

The Search for Extraterrestrial Intelligence (SETI) Microwave Observing Project is scheduled to begin operation on Columbus Day 1992. SETI will employ state-of-the-art signal processing technology to search for an artificially generated signal coming from interstellar space. Programs and computer chips custom made for a SETI spectrum analyzer may find applications in many other fields (Figure 16). The SETI analyzer requires a digital system that performs on the order of 10 billion operations per second, which vastly exceeds the speed of existing super-computers. Its high-speed ability to discriminate among many millions of frequencies could find applications in medicine and geology, both of which use high frequency sound waves as diagnostic or exploratory tools. Physicians and geologists could process ultra-

sound signals with greater resolution, without having to rely on more costly super-computers.

PLAID (Panel Layout Automated Interactive Design), one of the tools used by NASA human performance researchers, is a group of related computer models, databases and graphics, which can construct and juxtapose graphic models of humans and objects, vary the positions and the viewpoint (Figures 17 and 18). It can depict the scene as viewed from any point in space as either by the unaided eye or by a camera. A built-in collision-detection algorithm that informs the user if two objects are trying to occupy the same space helps to determine equipment layout and verify whether a human will fit into a small space, for example, to make repairs. The program is also used to investigate reach envelope, i.e., to determine whether an operator can reach a pedal or switch in a given configuration. After requests from the private sector, PLAID was released for distribution. An updated version is now being prepared. PLAID's potential terrestrial applications include equipment design (human modelling for fit, reach, and access) and architectural layout.

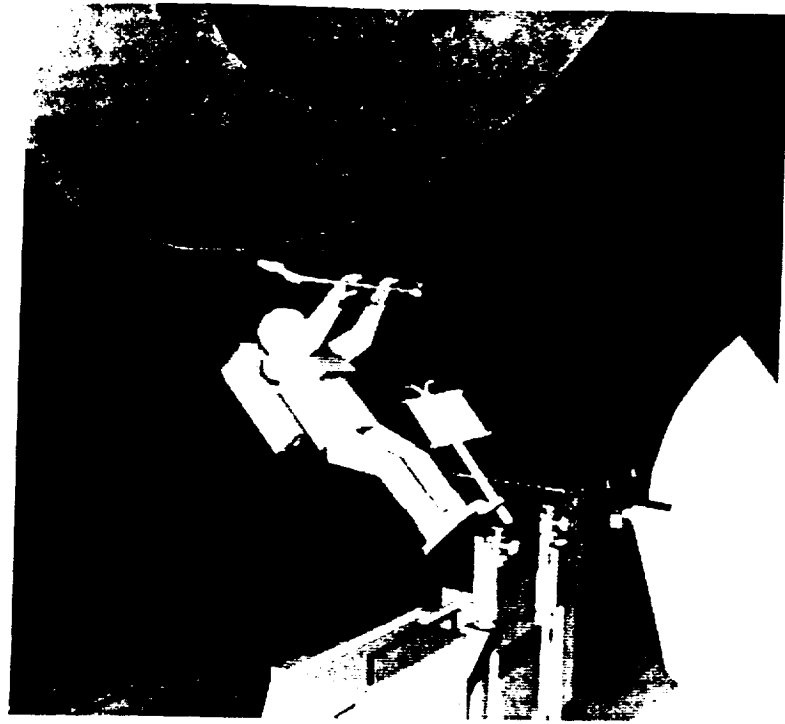


Figure 17. A computer model generated by PLAID shows a Shuttle crewmember engaged in extravehicular activity.

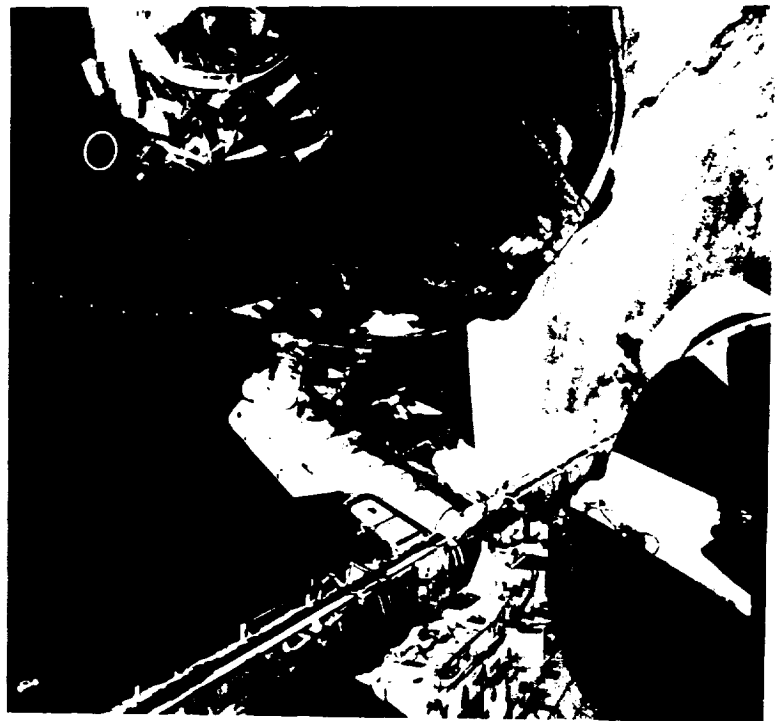


Figure 18. A corresponding photograph taken in space shows PLAID's ability to realistically model complex tasks.

Life Sciences Applications: Environmental Monitoring, and Safety

Future space missions will require humans to spend very long periods—up to 3 years for a mission to and from Mars—in closed environments, both in spacecraft and in planetary habitats. Life support and environmental monitoring systems, with long-term efficiency, will be critical to the health and well-being of the human crewmember in these settings. Therefore, NASA's research and technology programs in the area of environmental monitoring are directed towards ensuring air and water quality, monitoring microbial and toxicant levels, removing particulates, developing procedures for decontamination, and ensuring overall habitability. Space systems must be compact, lightweight, cost-effective and energy-efficient, functional in space and in the partial gravity of the Moon and Mars.

Advanced life support systems for exploration will require technology development in a variety of areas with high spinoff potential: vastly improved air and water quality sensors, air revitalization systems, and means to capture and dispose of airborne particulates. Advancing the state of the art in closed-loop systems holds the possibility of evolving numerous environmental monitoring technologies, filtration devices, and contaminant sensors.

Applications may be foreseen for improved environmental controls in large commercial complexes (for example, to alleviate the "sick building" syndrome) where air quality is poor. NASA's Ames Research Center has joined with the University of Florida and the private sector in a pioneering agreement under the American Technology Initiative Program that could have significant potential for use in monitoring indoor

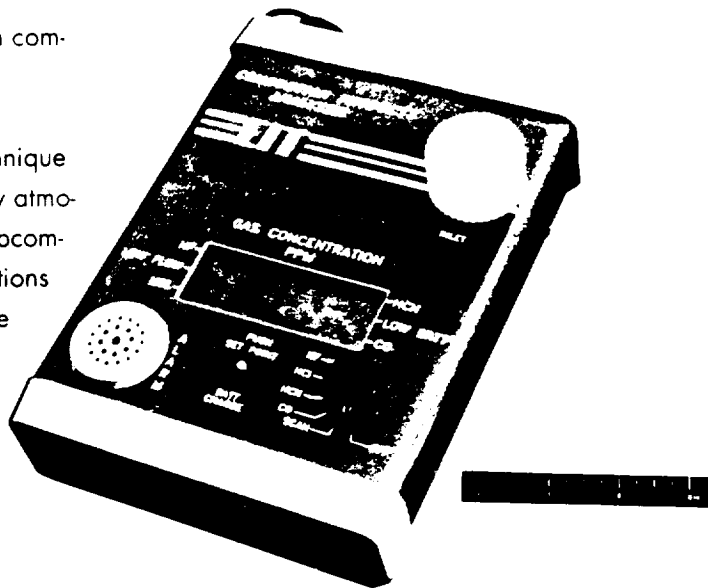
pollution in office buildings. This research will investigate the feasibility of an artificial intelligence-based system for monitoring closed-loop life support systems. Research at Ames involves the development of an expert system to control the various steps in the chemical analysis and identification of volatile, potentially hazardous, compounds.

The Volatile Organic Detector and Analyzer (VODA) is an environmental monitoring device that has been developed to warn space crews of low levels of volatile organic compounds, not readily detectable, that might be present in the Shuttle or Space Station Freedom. Compact, automated, and battery-operated, the VODA can identify and quantify up to 30 targeted volatile organic compounds in a spacecraft atmosphere. These attributes lead to numerous potential applications on Earth, including environmental monitoring and the detection of leaks and spills at toxic waste sites, manufacturing facilities, and community exposure studies.

An onboard fire could release potentially toxic gases into the closed atmosphere of a spacecraft. The Combustion Products Analyzer (CPA) (Figure 19) is designed to provide an early warning of combustion events such as fire or overheating equipment, and to monitor the concentration of gases in order to rapidly assess the effectiveness of decontamination efforts and air quality following a fire, or spills and leaks of toxic materials. The CPA's compact size and portability make it useful as a convenient monitoring device for firemen or chemical plant maintenance employees in hazardous situations. Now flown regularly on the Space

Shuttle, the CPA may find application on commercial or military aircraft.

Gas chromatography, an analytical technique that has been used to examine planetary atmospheres, will play an important role in upcoming space missions that will pursue questions related to the biochemistry of life and the development of planets. Gas chromatography yields information on the composition of a substance by separating and measuring the fractions of certain compounds from more complex mixtures.



On Earth, gas chromatography finds application in a variety of situations that require the rapid detection and analysis of substances, such as laboratory analysis of toxic and unknown substances, and environmental monitoring.

Under a grant from the NASA Life Sciences Division and Ames Research Center, researchers have achieved advances in miniaturization of gas chromatography technology (Figure 20). This research activity incorporated "micromachining" techniques (i.e., using very small and accurate tools) that have allowed the fabrication of extremely small and precise physical structures on a silicon wafer. The end product was an entire working gas chromatograph—consisting of a gas sampling valve, a column, and a detector—fabricated on a single silicon wafer. This prototype represented a decrease in weight of three-to-four orders of magnitude from commercial devices, and was two orders of magnitude more sensitive when measuring the same substances. This development effort subsequently formed the basis for a commercial enterprise that markets a portable gas chromatograph for field use.

Portable life support systems for extravehicular activity and excursions on planetary surfaces will require reductions in weight, power, and volume—along with increased reliability.

Figure 19. The Combustion Products Analyzer (CPA), routinely flown on Space Shuttle missions, could have toxicological applications on Earth.

Among the promising Earth applications for this technology is improved disaster management. Combining thermal materials research with advanced portable life support units can lead to technologies that will assist relief workers, particularly in extremely hazardous situations, such as oil well fires, firefighting, rescue of air crash victims, and clean-up of toxic spills. Strides in portable life support technology should also enhance the safety and efficiency of undersea operations, harvesting, and mining.

Life support and space suit technology from the Apollo and Space Shuttle eras has found application in a new firefighting breathing apparatus (Figure 21), which fire authorities acknowledge to have reduced injuries by some 90 percent in applicable situations.* Advantages of the resulting unit, which is used in virtually every metropolitan area, include reduced weight, extended durability, and improvements in the helmet, mask, and air depletion warning device.

An Exploration of Benefits from NASA "Spinoff."
Study conducted by Chapman Research Group, Inc.
National Aeronautics and Space Administration,
Washington, DC, June 1989.

Figure 20 (Below) The photograph shows the progressive miniaturization of gas chromatography technology. At the far left is an old version of a thermoconductivity detector (TCD), capable of detecting trace contaminants at a level of several parts per million (ppm). Second from left is a TCD flown on planetary missions in the mid-1970s. Second from right is a mock-up of a commercial metastable ionization detector (MID), with an improvement in sensitivity of about three orders of magnitude over previous instruments. Finally, at far right is a newly designed MID. This very small component allows the detection of trace contaminants at the part-per-billion range. In addition to its extremely high sensitivity, this detector responds to all types of chemical species in the vapor phase. Portable analytical equipment using this newer, more miniaturized and more sensitive detector will be useful for the detection of toxic vapors in hazardous environments associated with industrial sites and chemical spills.

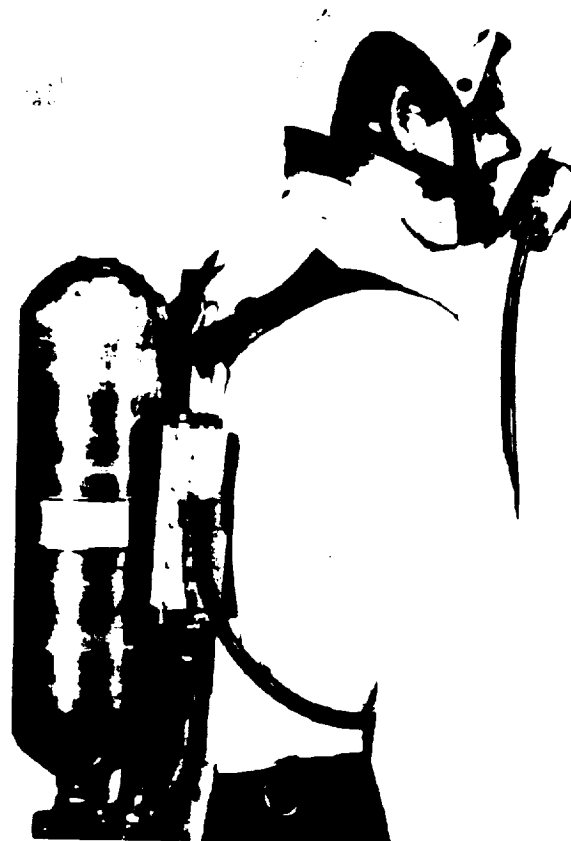
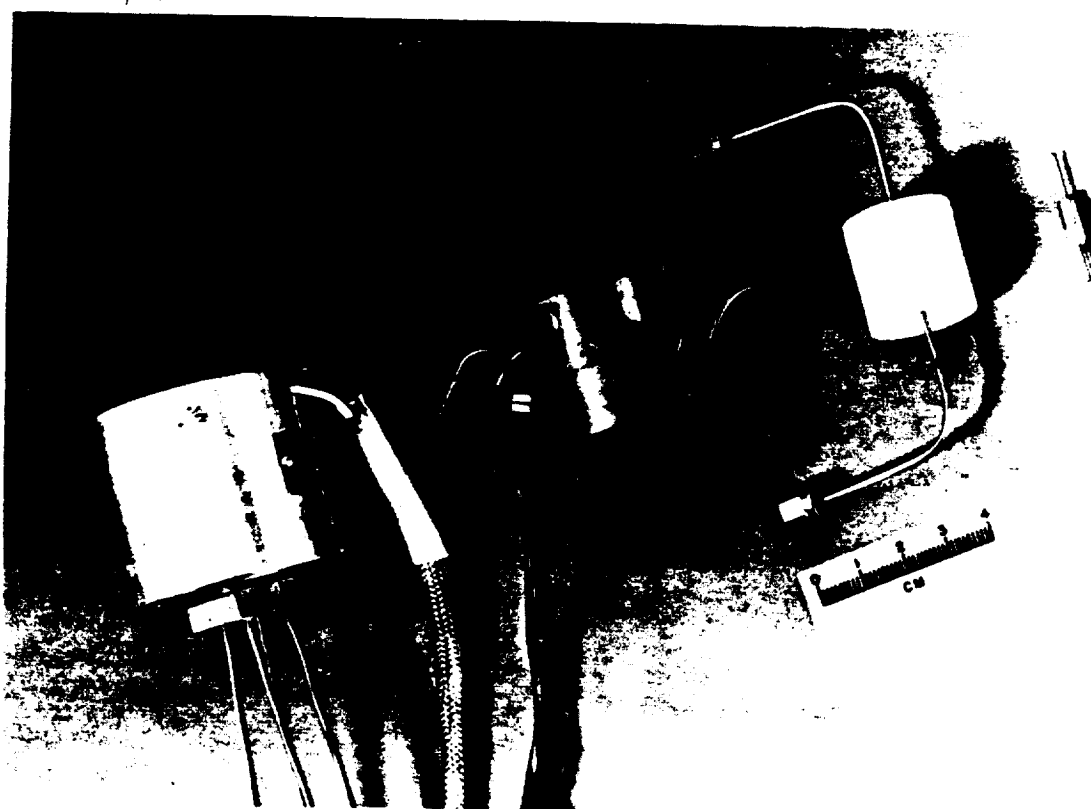


Figure 21. (Above) This breathing apparatus for protection against smoke inhalation is the result of adapting aerospace materials and technology to create lighter, less cumbersome firefighting equipment.



Life Sciences Applications: Agricultural Productivity

As human exploration missions in space grow longer and occur at greater distances from Earth, closed-loop life support systems will be required to eliminate the need for costly and logistically complex resupply. Researchers in the Life Sciences Division's Controlled Ecological Life Support System (CELSS) Program are developing a bioregenerative life support system based upon photosynthesis that will provide food, potable water, and air over long periods in the closed environment of the spacecraft or planetary habitat. The system is currently in the breadboard stage at Kennedy Space Center.

Problem areas in U.S. agriculture include disproportionately high input requirements (i.e., energy, fertilizer, irrigation, pesticides, etc.) per unit of product. With current agricultural methods for wheat, approximately one acre of crop is required to produce sufficient food energy to supply one person per seasonal harvest. CELSS experiments in controlled environments have reduced that requirement to 0.002 acre/person, or 500 people per acre.

The CELSS Program (Figures 22 and 23) is designed to promote a greater expression of the genetic potential of crops commonly used in field agriculture, and results to date indicate that such crops have a much greater productivity potential than is presently realized. CELSS crop-growth experiments in closed chambers have exceeded world record field yields by 200-300 percent and reduced seed-to-harvest cycles by more than 25-30 percent. Studies of environmental influences on plant development and yield, together with careful control of light, water, and other environmental parameters, have dramatically increased productivity per

unit input to the system. Crops grown under these conditions are of consistently high quality, and production has been predictable. Although some CELSS techniques, such as enriching the carbon dioxide in the closed atmosphere, may not apply in the open field, the basic knowledge gained from this applied research is of great value to agriculture in general. The eventual identification of environmental conditions that allow optimum yield and productivity will also be of use to the controlled environment agriculture industry in particular.

The design of small, efficient plant growth chambers may have practical value in urban areas or extreme environments such as the Antarctic or deserts. And, aside from its importance in food production, CELSS research may provide a model of other closed environments such as modern insulated houses, where plants could act as natural "scrubbers" to remove air pollution.

The CELSS Program is examining automation and robotics techniques for growing crop plants in space. Automated crop production methods will be of value to the commercial hydroponic farming industry: increasing the level of automation could increase production and profits.

Among the other benefits anticipated from CELSS research are advanced lighting technologies, and technologies that enable computer control of multiple systems, allowing for the integration and monitoring of such factors as temperature, lighting, nutrient supply, humidity, etc. CELSS research may also result in advances in nutrient delivery systems for hydroponic plant growth. Waste management technologies for

the limited spacecraft area may, in turn, lead to advanced waste management technologies for solid and liquid waste processing.

Technology developed for the "Salad Machine," a CELSS applications research project underway at NASA Ames Research Center, could provide fresh vegetables in harsh environments automatically – polar research stations,

petroleum exploration platforms, and remote Alaskan villages – where costs and other factors associated with importing fresh foods are prohibitive. The Salad Machine (Figure 23) may also provide a basis for future technologies that could conceivably be used in homes for the production of fresh vegetables unaffected by, for example, pesticides.

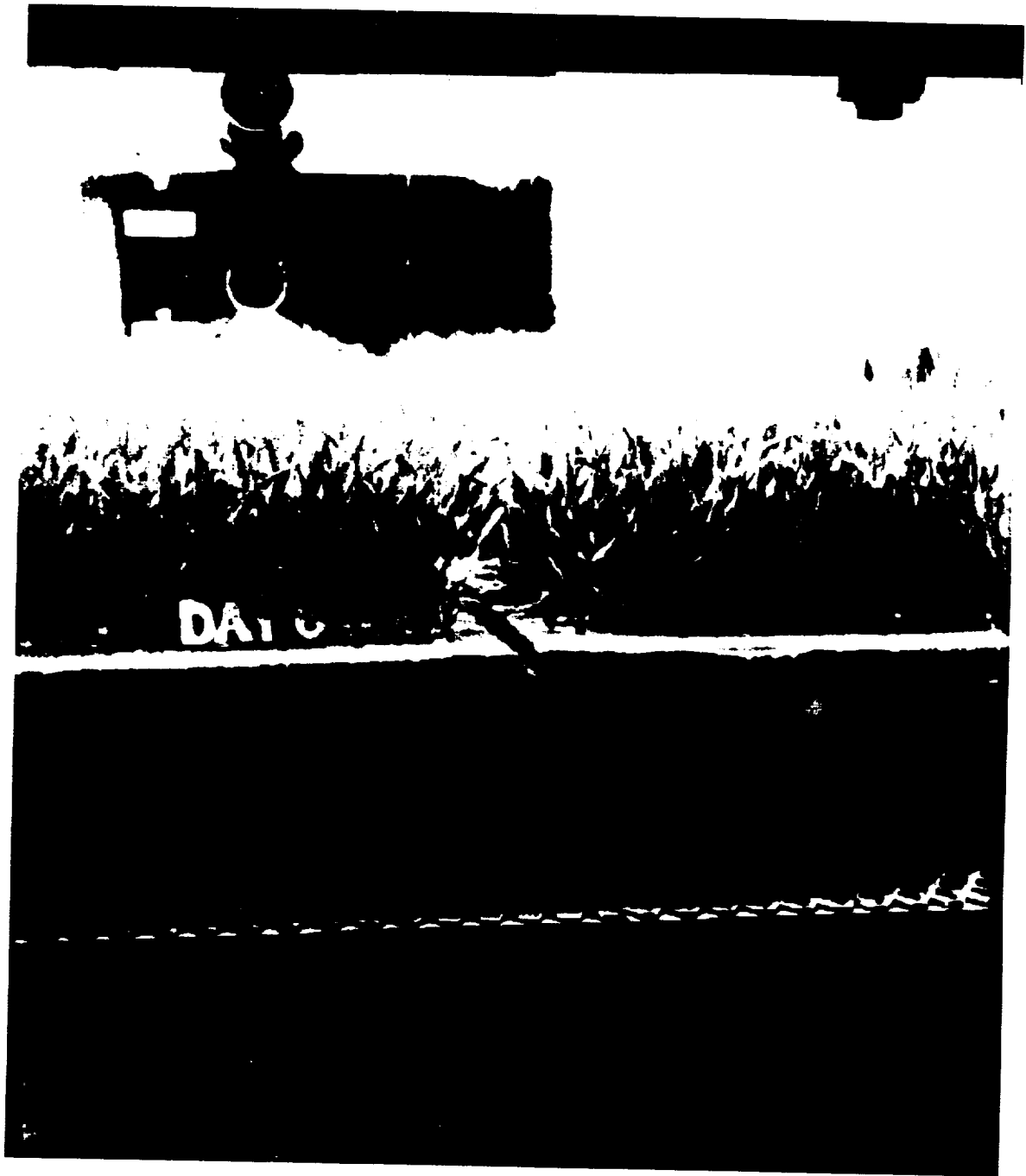


Figure 22. Closed chamber wheat production (day 6) using a controlled hydroponic nutrient delivery system.

In addition, investigations with plants, conducted by both the CELSS and the Life Sciences Division's Space Biology Program, could lead to improved plant growth systems that better conserve soil, water, labor, and energy; improved food storage; and advances in breeding and genetic engineering of new plants. Hormonal constraints on the cloning process on Earth are neutralized or more easily manipulated in space; thus, cloning of new types of plants in space that are difficult to propagate on Earth would be a boon to agribusiness.



Figure 23. Hydroponically grown lettuce being removed from the KSC "Breadboard" biomass production chamber in which it was grown.



Figure 24. NASA's Salad Machine allows the cultivation of fresh vegetables in areas where harsh weather conditions and geographical and other factors prohibit the growth or import of fresh foods.

Life Sciences Applications: Environmental Protection

NASA's Biospheric Research Program applies the unique planetary perspective afforded by space to the direct study of Earth's environment. Aircraft observations are combined with remote sensing from space and data collection on the ground to study the operation of different ecosystems, and to determine how these ecosystems are being altered by human activity. Among the questions being addressed are the potential effects of global climate change, the impact of large-scale wildfires, and the transmis-

sion of vector-borne disease, specifically malaria. The latter brings the capabilities of NASA's space technology to a question of major importance to terrestrial health, particularly in Third World nations.

Determining the Effects of Wildfires

In the continental United States, 130,000 fires devastate the natural landscape each year, releasing approximately 25 million metric tons of ash into the atmosphere. While wildfires can have some beneficial environmental effects, such as promoting nutrient cycling in soils, they also can adversely affect ecosystem productivity. Large-scale fires also release trace gases (e.g., carbon dioxide, methane, and nitrous oxide) that contribute to the "greenhouse effect," or global warming.

Fire temperatures are believed to be correlated with nutrient cycling and the emission of trace gases, but, traditionally, smoke or inaccessible terrain has made it difficult to obtain reliable information on fire intensity and temperature, size, pattern, and gas production. Another central problem has been a lack of information on the materials generated by fires of different intensities and durations.

A study of characteristics and emissions of major wildfires is currently being conducted at NASA Ames Research Center. This study will help improve techniques for fire monitoring and control and add to our knowledge of the environmental impact of large-scale fires. New sensors are being designed and built that will accurately measure fire temperatures from air-



Figure 25. In 1988 NASA aircraft helped in the fight to monitor the massive wildfire that swept Yellowstone National Park, and in the effort to understand the environmental effects of the fire.

craft- and spaceborne platforms. This technology will provide data on the effects of wildfires that can be used in local and global models of climate change.

Airborne remote sensing offers a number of advantages over conventional fire monitoring practices, including greater area of coverage, better penetration of smoke, and imagery transmission over long distances. These advantages were demonstrated during the massive wildfires in Yellowstone National Park in 1988, when aircraft from NASA Ames Research Center relayed images of burned areas and the movement of the fire front to local receiving stations (Figures 25 and 26). The Yellowstone missions complemented ongoing efforts at Ames to understand the environmental impact of fires. Data obtained from airborne instruments are being combined with conventional field measurements and analyzed to determine intensity, rate of spread, and severity of the fires.

Forest Management

Remote sensing data are contributing to more accurate mathematical models of how forests function. Measurements are first taken on small sites, such as a stand of trees, and then extended to estimate characteristics of larger areas, which can be detected in satellite images. Certain forest characteristics, such as leaf surface area, are combined with other spatial measurements, such as soil maps and meteorological data, to create models that can be used to predict such forest processes as growth or productivity.

The Oregon Transect Ecosystem Research Project is an interdisciplinary research project whose goal is to measure and model the biological regulation of carbon, nitrogen, and water flux in six temperate coniferous forest ecosystems in west-central Oregon. In recent years, project scientists have developed several models of ecosystem processes that use vari-

ables derived from remote sensing data for estimating key ecosystem fluxes. At the same time, the research team has gained an understanding of the relationships among key ecosystem parameters and remote sensing data.

The coniferous forests that occupy approximately one-third of the land area of the western United States are among the most productive in the world. The leaf surface area of the forest canopy is related to the exchange of carbon dioxide, water, and oxygen. Sophisticated sensors on NASA aircraft and remote sensing data gathered by Landsat satellites have been used to estimate the leaf area index of these forests. The close correlation between leaf area and remotely sensed data demonstrates the potential of these techniques to estimate biogeochemical



Figure 26. This photograph from NASA's ER-2 aircraft shows an especially large smoke plume over West Yellowstone Park, Montana.

cycling characteristics of coniferous forests over regional scales.

Lignin, a compound in leaves, affects how plant canopies reflect sunlight. Recently it has been shown that the concentration of lignin in a plant canopy can be measured by aircraft sensors. The concentration of lignin in leaves is inversely related to the rate of nitrogen turnover in the soil, which in turn affects soil fertility and biological productivity.

Our ability to monitor ecological processes on regional and global scales is subject to the limitations of technology and our knowledge of these processes. The new generation of experimental, high spectral resolution sensors is capable of acquiring information specific to selected ecosystems and integrating ecological information from a large area into a single image or series of images.

Methane Production and Global Climate

The concentration of one of the greenhouse gases, methane, has increased rapidly over the last century, and continues to increase at a rate of approximately 1 percent per year. Knowledge of natural methane sources (e.g., wetlands, rice fields, cattle) is limited, and estimates of annual methane production from different ecosystems have been based largely on incomplete data.

In 1986, a research effort was initiated to estimate methane emissions from the Alaskan tundra. This 3-year program included collection of methane samples from wet and dry tundra sites, acquisition of ground data, and development of regional estimates. Remote imagery was used to identify different land cover types in the tundra, and these land cover types were then related to variations in ground measurements of methane production. The results formed the first "map" of methane production for the region.

The ultimate goal is to model and estimate methane production on a global scale, and determine the potential effect of global change. Such studies are vital to our understanding of how methane production and global climate affect one another.

Pollution Control

Origin-of-life studies conducted within NASA's Exobiology Program have shown that, during heating, amino acids order themselves nonrandomly into ordered thermal proteins. This process is as precise as, and may be more precise than, the modern sequencing that occurs under the stewardship of RNA/DNA. This research presents possibilities for biotechnology, including the direct production of certain proteins by heating the proper amino acids. Novel and useful compounds, partially unique but related to those that have arisen over billions of years of evolution, may be created in the laboratory and used in medicine and other fields. Some thermal proteins have been shown to be biodegradable and biocompatible, and may thus play a part in solving problems associated with terrestrial waste and pollution control, in which natural proteins have already provided some useful solutions.

Predicting the Spread of Disease

Malaria remains a serious and widespread global health problem despite extensive efforts to eradicate the disease. Currently, half of the world's population is at risk. According to the World Health Organization, 270 million people suffer from malaria at any given time, and each year approximately one million die from the disease, most of them children in tropical regions. To compound the problem, changes in land use have brought outbreaks of malaria to areas previously unaffected. Malaria is transmitted to humans by the *Anopheles* mosquito, which carries the malaria parasite, *Plasmodium*; however,

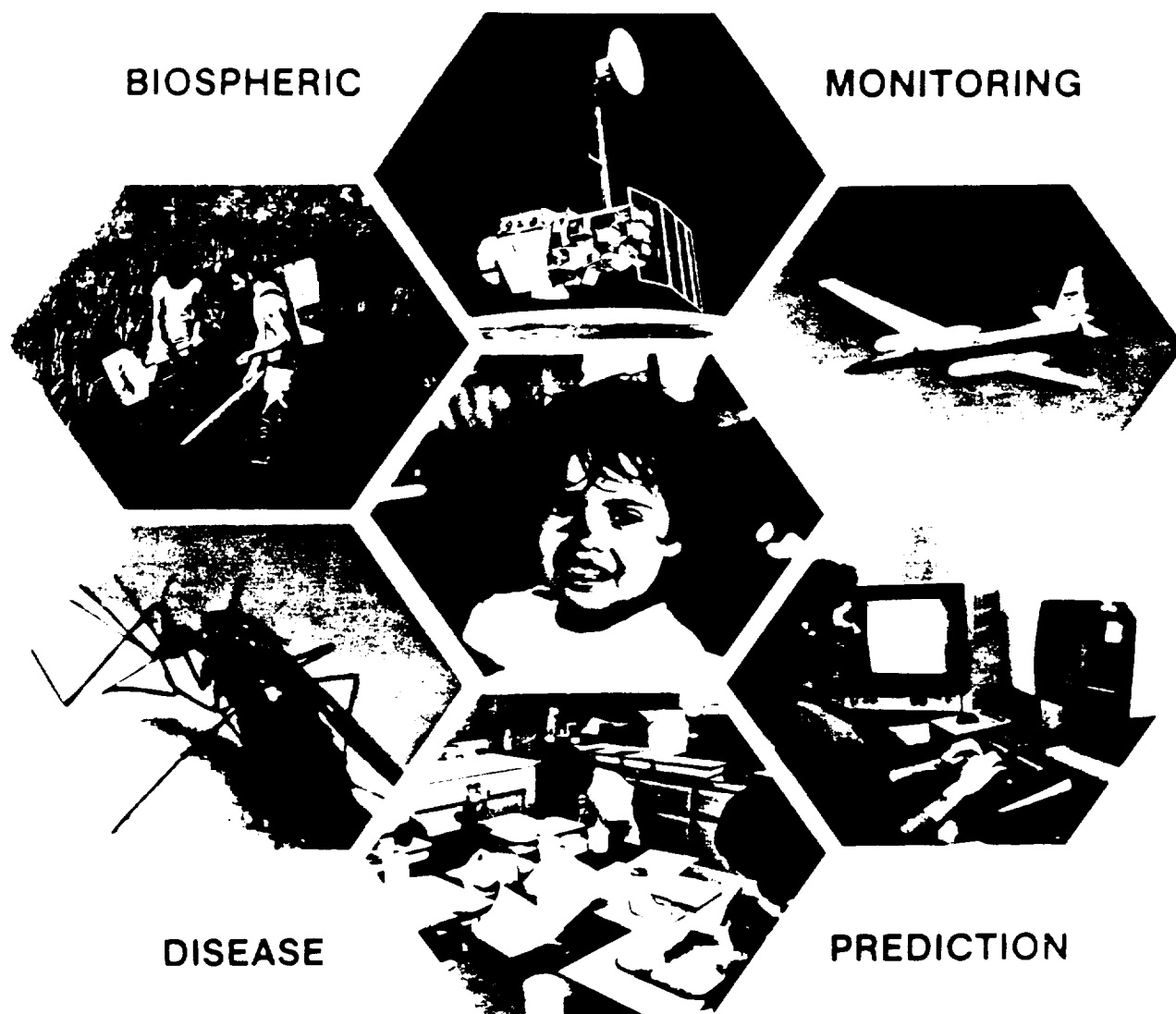


Figure 27. NASA's Biospheric Monitoring and Disease Prediction Project seeks to better predict outbreaks of malaria through remote sensing, collection of ground data, computer and laboratory analysis. -

the dynamics of disease transmission differ depending upon geographic location, mosquito species, and human population.

In 1985, NASA's Life Sciences Division, in cooperation with international health agencies, initiated the Biospheric Monitoring and Disease Prediction Project at Ames Research Center to study malaria (Figure 26). Using remote sensing technology, the program's goal is to model the relationship between malaria and its environment, in order to better predict where and when disease outbreaks will occur. This predictive information will help already over-burdened

health agencies in their efforts to control outbreaks of the disease.

Satellite imagery allows the identification and mapping of vegetation associated with the larval habitats of several mosquito species. The Biospheric Monitoring and Disease Prediction Project, however, goes beyond the goal of habitat mapping. Careful ground measurements, coupled with this remote sensing data, allow investigators to identify which environmental variables influence mosquito populations. Models help clarify the relationship between the spread of malaria and the remotely sensible en-

vironmental variables that influence mosquito population levels. Eventually, these models will be utilized to produce maps that describe the risk for malaria transmission over specific areas. The methods developed in this project will be made available to international users to help control malaria worldwide.

The first phase of the project was conducted in California, where the western malaria-bearing mosquito, *Anopheles freeborni*, breeds in rice fields. The results of a joint NASA/University of California study in 1985 indicated that the abundance of anopheline larvae was associated with specific vegetation characteristics of the fields, such as green-leaf area, which could be correlated with and monitored by remote sensing data. The study determined that rice fields that developed rapidly early in the growing season had higher anopheline larva populations than those that developed more slowly. A more extensive study in 1987 combined remote sensing measurements of early canopy development with distances measured between rice fields and livestock pastures (i.e., bloodmeal sources). The results indicated a clear distinction between high and low mosquito-producing fields. With this data, high mosquito-producing fields were predicted with close to 90-percent accuracy 2 months prior to a mosquito population peak. These predictions could be used to improve mosquito control measures.

Phase II, now underway, will produce a malaria risk map for the Pacific coastal plain of Chiapas, Mexico, an area of active malaria transmission. Studies identified two malaria-bearing mosquitoes with distinctly different habitats. Remote sensing data are being used to study land cover and map the potential mosquito habitat of the species that is particularly abundant in the wet season. When compared with patterns of human settlement, areas of potential malaria risk can be pinpointed.

The methods developed in this study will help control outbreaks of malaria worldwide. Future plans call for extending the findings of the California and Mexico studies to other regions of the world troubled by insect-borne disease. Space Station Freedom and NASA Earth Observing System platforms will provide spectral and spatial data over large areas of the globe where vector-borne disease constitutes a health problem.

Bibliography

- Haggerty, James J. Spinoff 1990. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, 1990.
- Haggerty, James J. Spinoff 1989. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, August 1989.
- Haggerty, James J. Spinoff 1988. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, August 1988.
- Haggerty, James J. Spinoff 1987. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, August 1987.
- Haggerty, James J. Spinoff 1986. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, August 1986.
- Haggerty, James J. Spinoff 1985. National Aeronautics and Space Administration, Office of Commercial Programs, Technology Utilization Division. NASA Headquarters, Washington, DC, August 1985.
- Haggerty, James J. Spinoff 1984. National Aeronautics and Space Administration, Office of External Relations, Technology Utilization and Industry Affairs Division. NASA Headquarters, Washington, DC, July 1984.
- Haggerty, James J. Spinoff 1983. National Aeronautics and Space Administration, Office of External Relations, Technology Utilization and Industry Affairs Division. NASA Headquarters, Washington, DC, May 1983.
- Haggerty, James J. Spinoff 1982. National Aeronautics and Space Administration, Office of External Relations, Technology Utilization and Industry Affairs Division. NASA Headquarters, Washington, DC, April 1982.
- Haggerty, James J. Spinoff 1981. National Aeronautics and Space Administration, Office of Space and Terrestrial Applications, Technology Transfer Division. NASA Headquarters, Washington, DC, April 1981.
- Haggerty, James J. Spinoff 1979. National Aeronautics and Space Administration, Office of Space and Terrestrial Applications, Technology Transfer Division. NASA Headquarters, Washington, DC, February 1979.
- Space Life Sciences—A Status Report. National Aeronautics and Space Administration, Office of Space Science and Applications, Life Sciences Division. NASA Headquarters, Washington, DC, February 1990.
- Life Sciences Report 1987. National Aeronautics and Space Administration, Office of Space Science and Applications, Life Sciences Division. NASA Headquarters, Washington, DC, December 1987.
- Life Sciences Accomplishments. National Aeronautics and Space Administration, Office of Space Science and Applications, Life Sciences Division. NASA Headquarters, Washington, DC, December 1986.
- Life Sciences Accomplishments. NASA Technical Memorandum 88177. National Aeronautics and Space Administration, Scientific and Technical Information Branch. NASA Headquarters, Washington, DC, September 1985.
- Bioengineering and Rehabilitation. NASA EP-216. National Aeronautics and Space Administration, Technology Division, Terrestrial Applications Program. NASA Headquarters, Washington, DC, 1985.
- Diamond, Patricia F., Ph.D. NASA completes tissue model in a microgravity bioreactor. *Genetic Engineering News*, April 1991. Mary Ann Liebert, Inc., Publishers, New York, New York.
- Chapman, Richard L., Lohman, Loretta C., and Chapman, Marilyn J. An Exploration of Benefits from NASA "Spinoff." Chapman Research Group, Inc. Littleton, CO. June 1989.
- Manned Space Flight Benefits. National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, TX, June 1987.
- Dahir, Mubarak, S. The Big Queasy. *Final Frontier*. July-August 1991.
- American Association for the Advancement of Science (AAAS). Project 2061: Science for All Americans. Summary. AAAS, Inc. Washington, DC, 1989.

